Management of water regimes in River Red Gum *Eucalyptus camaldulensis* wetlands for waterbird breeding

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ABSTRACT

This study investigated relationships between durations of inundation in River Red Gum wetlands and waterbird breeding, in particular the durations of flooding under nest trees that waterbirds need to breed successfully; and developed guidelines for managing water regimes in River Red Gum wetlands for waterbird breeding. The main study area was the middle section of the Murrumbidgee River in New South Wales. Average lag times between flooding under nest trees and first nests of Darter, cormorants, herons, egrets, Australian White Ibis and spoonbills ranged from two to four months following spring floods, and from four to seven months following autumn floods. The average lag times from flooding under the nest trees to first broods of ducks were one to two months, regardless of season of flooding. Average lag times to peak breeding of Darter, cormorants, herons, egrets, Australian White Ibis and spoonbills were three to five months following a winter/spring flood and six to nine months following an autumn flood. The equivalent figures for ducks were four months following a winter/spring flood and five months following an autumn flood. Taking egg laying, incubation of eggs and fledging of young into account, waterbirds need 5 to 10 months inundation under nest trees to complete breeding. Most Darters, cormorants, herons, egrets, Australian White Ibis and spoonbills nested at wetlands which retained water permanently in their deeper, open areas. In contrast, most ducks bred at wetlands which dried out fully between floods. Water levels in River Red Gum wetlands should be managed to provide breeding habitat for waterbirds by allowing the ground under the nest trees to flood for at least 5 to 10 months, and then dry back before the next flood. River Red Gums should not be flooded for longer than 18 months, but water can be retained permanently in deeper, open areas of wetlands.

Key words: Water regimes, River Red Gum, Wetlands, Breeding waterbirds.

INTRODUCTION

The aims of this study were to: (i) investigate relationships between waterbird breeding and durations of flooding in River Red Gum *Eucalyptus camaldulensis* wetlands; (ii) determine the lengths of flooding under nest trees that waterbirds need to breed successfully; and (iii) to develop guidelines for managing water regimes in River Red Gum wetlands in the Murray-Darling Basin for waterbirds.

Flows in most Murray-Darling rivers have been substantially reduced by river regulation and extraction of water for irrigation (Thomson 1992; Murray-Darling Basin Commission 1996). Such extraction has reduced frequencies, durations and extents of flooding in floodplain wetlands (Bren 1991; Maher 1993; McCosker and Duggin 1993; Kingsford and Thomas 1995; Cullen *et al.* 1996; Kingsford and Johnson 1998). Conversely, local control of water levels has permanently flooded many wetlands, often for water storage (Pressey 1986; Thornton and Briggs 1994; Murray-Darling Basin Commission 1996). Information on lengths of wetland flooding that waterbirds require to breed successfully is needed to evaluate, and then manage, the impacts of changed water regimes in rivers and wetlands on waterbird breeding.

Waterbirds take about three months (range for most species is 2.5–3.5 months) to lay and incubate their eggs and to fledge their young (Marchant and Higgins 1990). Some wetland managers have assumed that floods of this short length are sufficient for waterbirds to breed (Leitch 1989; Lugg 1993). This ignores the time lag between flooding under nest sites and initiation of laying by waterbirds. Other workers have added one month to cover this time lag, but failed to allow time for egg laying (Green 1994). The time lag between flooding under nest sites and commencement of egg laying will vary between species of waterbird, with wetland conditions elsewhere, and with the time of year that flooding commences. This time is needed by birds to prepare their nest, and prepare behaviourally, nutritionally and hormonally for breeding.

Over a decade ago, Briggs (1988) published guidelines for managing water regimes in inland wetlands in southern New South Wales, largely based on work by Maher and Carpenter (1984), Briggs and Maher (1985) and Crome (1986) (quoted in Beckman 1988). These guidelines recommended continuous inundation of wetlands for at least four to six months, periodic drying and no longer than four years of continuous flooding. Five years after Briggs' (1988) guidelines, Lugg

(1993:13) produced similar guidelines for periods of wetland inundation, which differed in one respect from those of Briggs (1988). He stated that wetlands should be flooded for a minimum of three to four months, whereas Briggs (1988) had stated that wetlands should be inundated for at least four to six months.

Recommendations to periodically dry out all wetlands in the Murray-Darling Basin may now be oversimplistic. Our increased understanding of Murray-Darling wetlands and their fauna in recent years has shown that relationships between wetland water regimes and wetland fauna are not simple (Gehrke 1992; Maher and Braithwaite 1992; Gehrke *et al.* 1993; Suter *et al.* 1994; Briggs *et al.* 1997). Recommendations to dry out all wetlands in the Murray-Darling Basin may now be simplistic because of increased extraction of water from Murray-Darling rivers (Murray-Darling Basin Ministerial Council 1995; Murray-Darling Basin Commission 1996; Thoms *et al.* 1996; Kingsford and Johnson 1998), and hence reduced wetland flooding since 1980 (the year when most of the work which underpinned Briggs (1988) concluded).

The study focuses on waterbirds breeding in River Red Gum wetlands. These wetlands are floodplain wetlands which comprise open areas of wetland interspersed throughout River Red Gum woodland. Such wetlands are common throughout the Murray-Darling Basin and provide major breeding habitat for many waterbirds (Briggs and Thornton 1995, references therein).

STUDY AREA

The main study sites were 10 wetlands on the floodplain of the Murrumbidgee River in inland New South Wales, between Wagga Wagga and Hay (Fig. 1). Bulls Run was a depression, Boggy Creek and Dixons Dam were spreading creeks, Cuba (also known as Gooragool), Sunshower, Uri, Wowong, Yarradda, Webbs and McKennas Lagoons were oxbow lagoons or billabongs.

The water regimes of the sites are described in Briggs *et al.* (1994, 1997). Bulls Run, Boggy Creek, and Sunshower, Uri and McKennas Lagoons did not retain water between floods, i.e., between breeding events. Conversely, Cuba, Wowong, Yarradda and Webbs Lagoons did retain water. Wowong retained water naturally between floods, whereas Cuba and Webbs Lagoons retained water pumped from the river. Yarradda Lagoon had a low regulator in the channel to the river, and held water for a long while after the water level

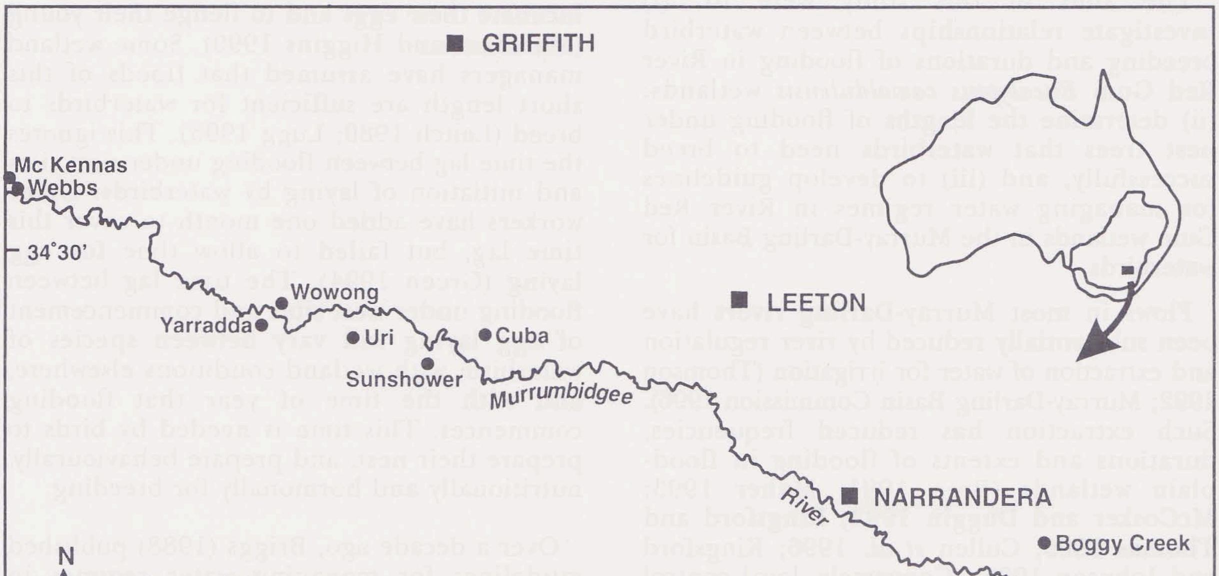

Figure 1. Map of the study sites on the Murrumbidgee River, and their locations within the Murray-Darling Basin and Australia. Wagga Wagga and Hay are approximately 20 kilometres to the east and west of the boundaries of the map respectively.

in the lagoon dropped below the height of the regulator. Dixons Dam generally retained water pumped from the river between floods, but dried out prior to the 1991/92 flood. Only the deeper, treeless areas of the wetlands held water between floods. Water receded from under the River Red Gums at all wetlands after floods, including wetlands which retained water in their open, deeper areas.

All the study wetlands contained open, treeless areas (inundated either permanently, or temporarily during floods), surrounded by live River Red Gums. During floods, rising water filled the deeper, treeless areas first and then inundated the ground under the surrounding River Red Gums. Some wetlands contained aquatic plants (mostly emergent spikerush *Eleocharis* sp., *Paspalum* sp. with some *Vallisneria americana*) (Briggs *et al.* 1997). Spikerush was particularly abundant in broad, flat wetlands which flooded for several months after complete drying. Dixons Dam, Boggy Creek and Cuba Lagoon also contained some dead River Red Gums (Briggs *et al.* 1997) at the edge of their open areas or scattered throughout them. Wetlands with heavily controlled water levels, where water levels rose and fell rapidly, and where natural flooding had little or no effect on water regimes (see Thornton and Briggs 1994; Briggs *et al.* 1997) were not included in this study.

Data on breeding times of waterbirds following flooding under their nest trees (River Red Gums) were also collected from two other sources (Crome 1986, 1988 and W. Johnson, NPWS, pers. comm. 1997). Crome's (1986, 1988) work was conducted in a River Red Gum wetland associated with Merrimajeel Creek, a distributary from the Lachlan River in inland New South Wales. Johnson's data were collected from River Red Gum wetlands in the Macquarie Marshes, also in inland New South Wales (see Kingsford and Johnson 1998).

METHODS

The study wetlands along the Murrumbidgee River were surveyed for breeding waterbirds during three flood (= breeding or survey) periods, in 1989/90, 1991/92 and 1993/94, by canoe, boat, wading and walking. Breeding waterbirds were surveyed during these three flood periods when the wetlands and surrounding areas of River Red Gum were flooded (see Fig. 2 in Briggs *et al.* 1997). Numbers of nests and broods were recorded at each wetland about every six weeks during the flood periods in these three years: from April/May 1989 to June 1990, from July 1991 to January 1992, and from August 1993 to April 1994 (Briggs *et al.* 1994).

Only those species of waterbirds which commonly breed in live River Red Gums were included in this study (Appendix 1). In this paper we use the name of the Orders, Pelecaniformes to refer to Darter and cormorants (excluding Great Cormorant which usually breed in dead River Red Gums, rather than live trees) (Briggs and Thornton 1995), and Ciconiiformes to refer to herons, egrets, Australian White Ibis and spoonbills. Ducks are in the Order Anseriformes.

Breeding observations of Pelecaniformes and Ciconiiformes were nests, including those being built, or with eggs or young. Breeding observations of ducks were broods. Broods were groups of young ducks attended by one or both parents, or an observation of broken wing behaviour by parent ducks indicating that young were nearby. Observations of nests or nesting behaviour (leaving or entering tree holes) of ducks were not included because duck nests are cryptic (usually in holes in trees), and cannot be surveyed reliably over large areas. Only waterbird species which had at least 10 nests or broods at peak breeding (the survey trip when most nests or broods were recorded for that species) were included in the analyses. All stages of nests and broods were recorded. Nests and younger broods were more common early in breeding periods, and older young were more common later. At peak breeding all nests were at incubation stage or later. Broods of ducks at peak breeding were spread over age classes.

Surveys at Boggy Creek in 1989 did not start until August. Breeding records for missed survey trips at that site were extrapolated from later results and from results at Bulls Run, which was a similar wetland with similar species and numbers of breeding waterbirds as Boggy Creek. At least 50% of the areas of open water, live and dead River Red Gums and emergent aquatic plants at each wetland were covered by each survey. Partial counts of broods within these habitats were extrapolated by area to give complete estimates for each site. Some broods were probably missed in 1993/94 at Bulls Run, Boggy Creek, and at Sunshower, Uri and McKennas Lagoons due to heavy growth of spikerush. At least 90% of parts of wetlands where Darter, cormorants, herons, egrets, Australian White Ibis and spoonbills species nested (River Red Gums near and over open water, Briggs and Thornton 1995) were surveyed. Eight of the 10 wetlands were surveyed for breeding waterbirds in all three flood periods. Uri and Yarradda Lagoons were not surveyed in 1989/90.

Water levels in the Murrumbidgee wetlands were recorded at their deepest points each survey trip. The level at which water reached the live River Red Gum was recorded at each site. Durations of flooding under the River Red Gums at each wetland were calculated graphically by superimposing the level at which water flooded into the live River Red Gum on the plot of actual water level over time (graphs are in Briggs *et al.* 1994; a schematic example of one of the graphs is shown in Fig. 2). At a few wetlands (Boggy Creek in 1991/92, Dixons Dam and Yarradda Lagoon in 1993/94), water had already reached the live River Red Gum by the beginning of the survey period. One month was added to the flood durations at these sites, if the time of flooding could not be inferred from the river or wetland hydrograph, or from other sources. We estimated the number of months from when water entered the live Red Gum to when first nests or broods, as well as to when the highest number of nests or broods (peak breeding) were recorded, for each species of waterbird at each wetland in each survey period. Information on number of months from flooding under nest trees (River Red Gums) to first and peak breeding of waterbirds nesting in River Red Gum wetlands was also obtained from W. Johnson (pers. comm.), and from Crome (1986, 1988). Crome (1986) recorded broods of ducks, and Crome (1988) recorded nests of other waterbirds (Darter, cormorants, herons, egrets, Australian White Ibis, spoonbills) with young or adults present.

RESULTS

Average lag times between flooding under nest trees and first nests of Pelecaniformes and Ciconiiformes ranged from two to four months following winter/spring floods and from four to seven months (with one record of zero months) following autumn floods (Table 1). The average lag times from flooding under the nest trees to first broods of ducks were shorter (one to two months) than for Pelecaniformes and Ciconiiformes, and they were not obviously greater following an autumn flood compared with a winter/spring flood (Table 1).

Average lag times between flooding under nest trees and peak number of nests of Pelecaniformes and Ciconiiformes varied from three to five months following winter/spring floods and from six to nine months following autumn floods (Table 2). The average lag times between flooding under nest trees and peak number of broods of ducks were four months following winter/spring floods, and five months following autumn floods (Table 2). The generalized relationship between flooding under nest sites and breeding in Pelecaniformes and Ciconiiformes is shown in Figure 2.

With all data combined for the eight Murrumbidgee sites for which data were available in the three survey periods, there was a positive relationship between average duration of flooding under nest trees in a breeding period and the total number of nests and broods of all waterbirds in that breeding period (Fig. 3). Broods of Australian

Table 1. Mean ($\bar{x}$) number and range of months between flooding under nest trees and first broods (ducks) or nests (other species) of waterbirds nesting in River Red Gum trees. Ranges are in months. n = number of records on which results are based. A record is one breeding season for one species at one site. Winter/spring floods commenced in June, July and September. Autumn floods commenced in March and April. The data are from Crome (1986, 1988), Briggs *et al.* (1994) and W. Johnson (pers. comm.). ND, no data. Original data are in Briggs *et al.* (1994).

	Season of flood					
	Winter/spring			Autumn		
Species	$\bar{x}$	range	n	$\bar{x}$	range	n
Pelecaniformes						
Darter	3	2–4	3	5	4–7	7
L. Bk. Cormorant	3	2–4	3	5	0–9	7
L. Pied Cormorant	2	2–3	8	4	1–7	12
Ciconiiformes						
Pacific Heron	3	2–3	2	5	4–7	5
Great Egret		ND		7	7	3
Intermediate Egret	3	3	1	6	5–6	2
R. Night Heron	4	4	1	6	5–7	3
Aust. White Ibis	3	3	1	5	4–7	5
Royal Spoonbill	4	4	1	7	4–9	2
Y. — billed Spoonbill	3	2–3	2	0	0	1
Anseriformes						
Pac. Black Duck		ND		2	1	2
Grey Teal	2	2	2	1	1–4	9

Table 2. Mean ($\bar{x}$) number and range of months between flooding under nest trees and peak number of broods (ducks) or nests (other species) of waterbirds in River Red Gum trees. Ranges are in months. n = number of records on which results are based. A record is one breeding season for one species at one site. Winter/spring floods commenced in June, July and September. Autumn floods commenced in March and April. The data are from Crome (1986, 1988), Briggs *et al.* (1994) and W. Johnson (pers. comm.). ND, no data. Original data are in Briggs *et al.* (1994).

	Season of flood					
	Winter/spring			Autumn		
Species	$\bar{x}$	range	n	$\bar{x}$	range	n
Pelecaniformes						
Darter	5	5–4	3	8	7–9	3
L. Bk. Cormorant	4	3–4	2	6	0–9	5
L. Pied Cormorant	3	2–4	7	6	4–9	10
Ciconiiformes						
Pacific Heron	5	4–5	2	7	5–9	5
Great Egret		ND		9	8–9	3
R. Night Heron		ND		7	7	1
Aust. White Ibis		ND		8	7–9	4
Y. — billed Spoonbill	5	4–5	2	6	6	1
Anseriformes						
Pac. Black Duck		ND		5	4–6	2
Grey Teal	4	3–4	2	5	1–6	9

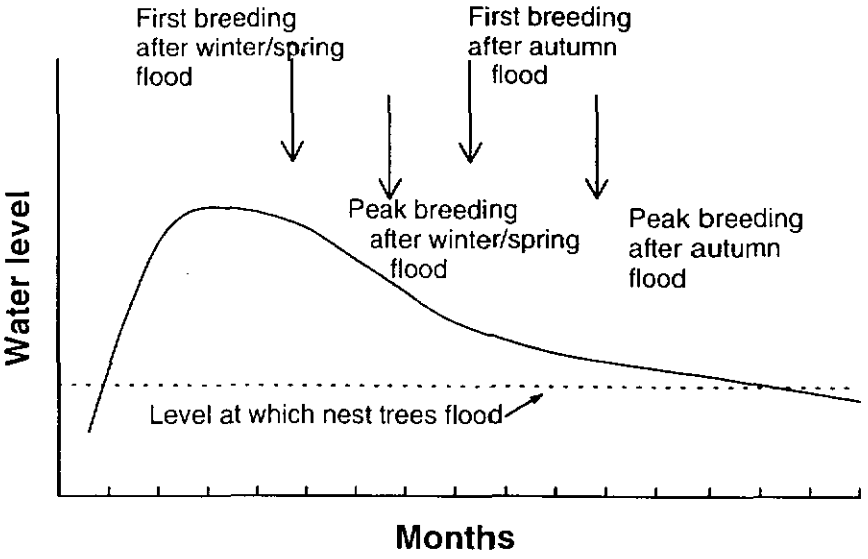
First breeding after winter/spring flood
First breeding after autumn flood
Peak breeding after winter/spring flood
Peak breeding after autumn flood
Water level
Level at which nest trees flood
Months

Figure 2. Generalized relationship between water level and Pelecaniformes (Darter, cormorants excluding Great Cormorant) and Ciconiiformes (herons, egrets, Australian White Ibis, spoonbills) breeding in River Red Gums.

Shelduck, Chestnut Teal and Australian Wood Duck were included in this analysis, although there were too few broods of these species for separate analyses. There were also positive trends between lengths of flooding at specific Murrumbidgee wetlands and number of nests and broods of waterbirds at these wetlands (Figs 4, 5, 6). In Pelecaniformes and Ciconiiformes these trends only occurred at wetlands whose deeper, open areas retained water between floods (Figs 4, 5). Ciconiiformes largely bred at wetlands which permanently retained water in their deeper areas (Fig. 5). The trend in ducks (Anseriformes) occurred at sites which dried fully between floods as well as at sites which retained water, but there was a pronounced response at two sites which dried fully between floods (Fig. 6).

Over the three flood periods, nest trees were inundated for an average (± s.e.) of one month longer (7.9 months ± 0.7, n = 5 sites) at the Murrumbidgee wetlands which generally retained water in their open areas compared

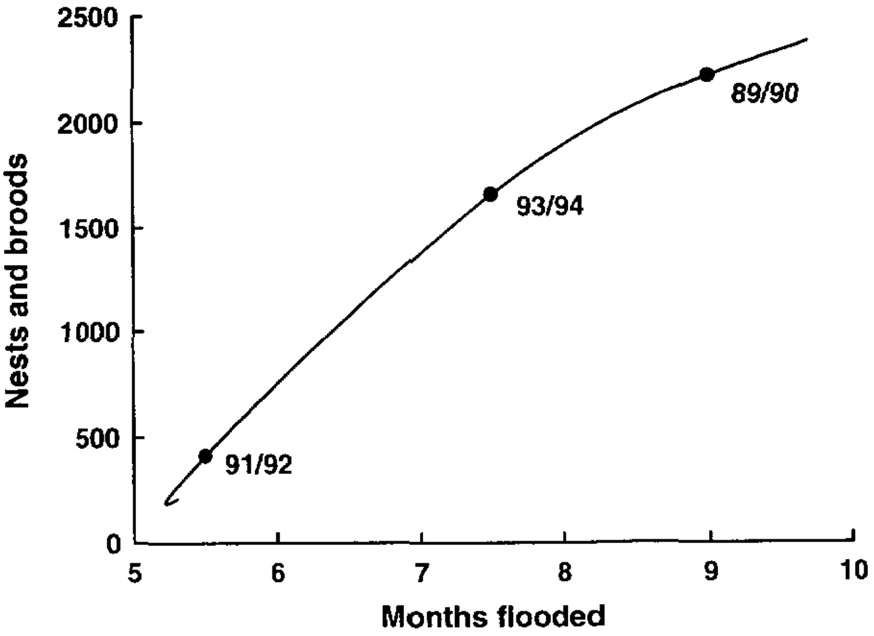

Figure 3. Relationship between total numbers of nests and broods of waterbirds that nest in live River Red Gums (see Appendix 1) and mean number of months of flooding under live River Red Gums at the eight Murrumbidgee wetlands which were surveyed in all three breeding periods of the study.

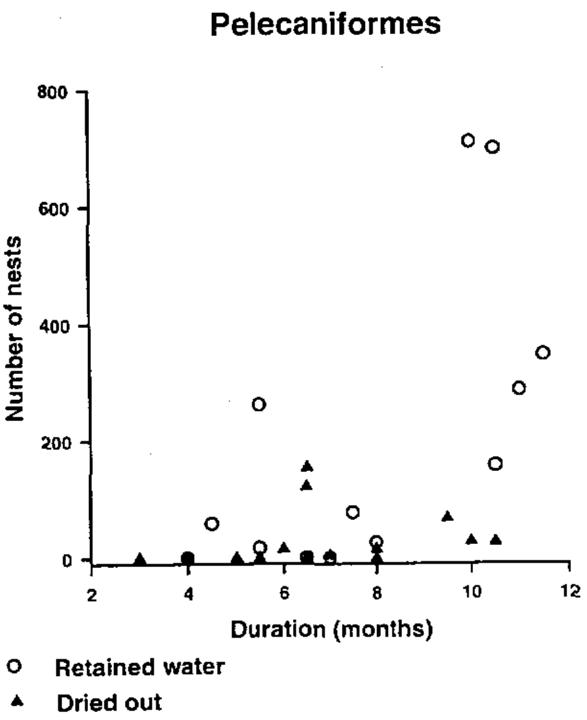

Figure 4. Number of nests of Pelecaniformes (excluding Great Cormorant) (see Appendix 1) at individual Murrumbidgee wetlands in each year of the study plotted against duration of flooding under the live River Red Gums at each wetland. Wetlands are distinguished by whether they dried out prior to the flood (= breeding period) or not.

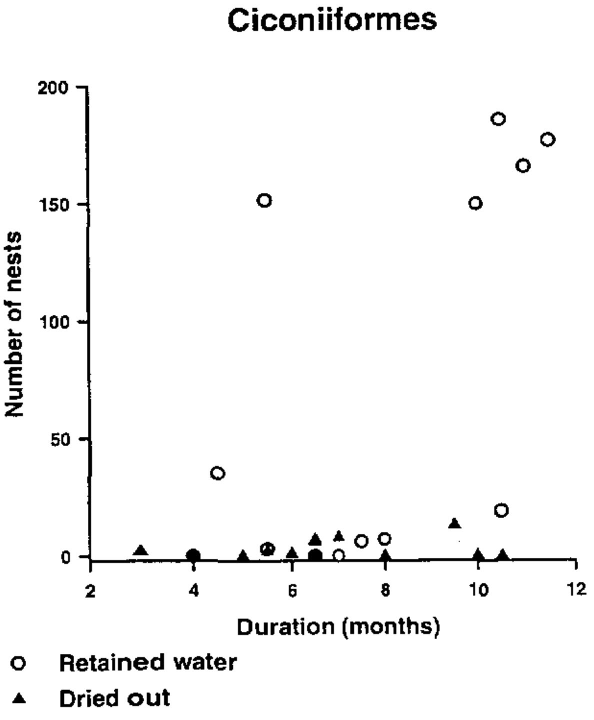

Figure 5. Number of nests of Ciconiiformes (see Appendix 1) at individual Murrumbidgee wetlands in each year of the study plotted against duration of flooding under the live River Red Gums at each wetland. Wetlands are distinguished by whether they dried out prior to the flood (= breeding period) or not. The outlier point (centre top of the graph) was the result of the water level falling very rapidly at Cuba Lagoon in 1993/94, due to water being pumped out of the lagoon.

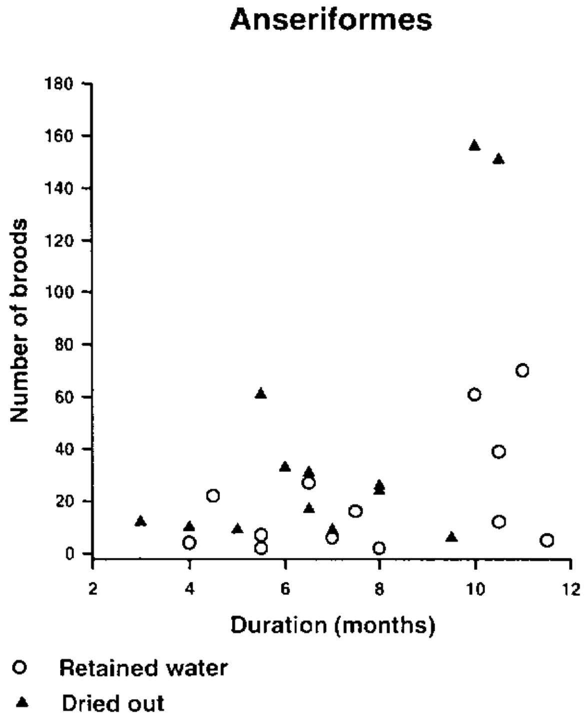
Anseriformes

Figure 6. Number of broods of Anseriformes (see Appendix 1) at individual Murrumbidgee wetlands in each year of the study plotted against duration of flooding under the live River Red Gums at each wetland. Wetlands are distinguished by whether they dried out prior to the flood (= breeding period) or not. Some broods could have been missed because of dense cover of spikerush at some of the wetlands which had dried out prior to flooding and then remained flooded for several months.

with nest trees at the wetlands which dried out entirely between floods (6.8 months ± 0.8, n = 5 sites). A greater average area of live River Red Gum was flooded for four months or longer at the sites which generally retained water between floods (64 ± 14.3 ha, n = 5), compared with the sites that dried out (27 ± 6.5 ha, n = 5).

DISCUSSION

Lag times between flooding under nest trees and nesting in waterbirds are considerably longer than previously recognized (Leitch 1989; Lugg 1993, but see Maher and Braithwaite (1992) who reported two months from flooding to first egg laying). The average times of incubation of eggs, and of fledging of waterbirds (other than ducks) in this study are one, and two and a half months respectively (Marchant and Higgins 1990). Depending on species, waterbirds (other than ducks) in this study took two to four months from inundation under the nest trees in winter/spring to first nests, and three to five months on average from inundation under nest trees to peak breeding. Thus, Darter, cormorants, herons, egrets, Australian White Ibis and spoonbills nesting in River Red Gum wetlands need at least five to eight months inundation under the nest trees to successfully complete breeding when flooding commences in winter/spring. This includes time for egg laying, as well as for incubation and fledging of young. These times increase by one to three months (average of two months) following autumn flooding. Therefore, 7 to 10 months inundation under the nest trees is required when flooding commences in autumn. The fastest breeding of the species studied (other than ducks) was Little Pied Cormorant, while the slowest was Great Egret. No data were available on lag times between winter/spring flooding under nest trees and nesting of this species.

Ducks can breed successfully on shorter floods than Darter, cormorants, herons, egrets, Australian White Ibis and spoonbills. Broods of ducks take almost two months to fledge. If we assume that broods were half grown at peak breeding, then ducks need five to six months to successfully complete breeding. This was not greatly influenced by season of flooding for ducks in this study.

River flows in virtually all rivers of the Murray-Darling system have diminished considerably, due to river regulation and extraction of water (Thomson 1992; Murray-Darling Basin Ministerial Council 1995). These lowered flows have reduced durations and frequencies of flooding in riverine wetlands (Bren 1991; Green 1994; Kingsford and Johnson 1998; D. Leslie, State Forests, pers. comm. 1997), except where water levels are locally manipulated (Pressey 1986; Green 1994; Thornton and Briggs 1994). Effects of reducing duration and frequency of flooding in riverine wetlands on recruitment in waterbirds are not well understood. The most obvious impacts would be expected on the waterbirds which require the longest time to reach peak breeding following flooding. These are the egrets, especially Great Egret. Egrets no longer breed along the Murray River in the numbers that they once did (Chesterfield *et al.* 1984; Maher 1993). This has been attributed to lack of deep spring floods (Chesterfield *et al.* 1984). A deep flood will generally maintain water under nest trees for longer than shallow floods. Our results conform with this observation.

Effects of reduced durations of wetland flooding on waterbird breeding will be less severe on species which take relatively short times to reach peak breeding after flooding under their nest trees. Reduced periods of wetland inundation are likely to adversely affect Great Egret more than Pacific Black Duck, Grey Teal and Little Pied Cormorant.

There was an overall positive relationship between duration of flooding under nest trees at the Murrumbidgee wetland sites and the number of waterbirds that bred, but the nature of the relationship varied between wetlands and between waterbird species. Kingsford and Johnson (1998) also found a positive relationship between flow in the Macquarie River (an index of flooding in the Macquarie Marshes) and the number of nests of waterbirds in the Macquarie Marshes.

The positive relationship between ducks and duration of flooding at the Murrumbidgee sites occurred at wetlands that dried out between floods and breeding events, and to a lesser extent at wetlands that retained water in their open areas. Most duck breeding occurred at two wetlands which dried out between floods. These results for ducks extend the earlier findings of Maher and Carpenter (1984), Crome (1986) and Briggs *et al.* (1997), which showed that ducks bred best when wetlands reflood after drying out.

The work of Maher and Carpenter (1984), Crome (1986) and Briggs and Maher (1985) formed the basis of the guidelines for wetland management in Briggs (1988). With minor modification, these guidelines still stand for ducks, in particular Pacific Black Duck and Grey Teal. This modification is to the following recommendation in Briggs (1988) that "wetlands should remain inundated for at least four to six months to ensure appropriate conditions — for successful reproduction of waterbirds". This recommendation now should be "the areas under nest trees in wetlands should remain inundated for at least five months to ensure appropriate conditions — for successful reproduction of waterfowl (i.e., ducks)".

This recommendation does not apply to waterbirds other than ducks. Most Pelecaniformes and Ciconiiformes, especially Ciconiiformes, bred at wetlands which retained water in their open areas. Relationships between durations of flooding under the nest trees and numbers of nests of Darter and cormorants (Pelecaniformes), and of herons, egrets, Australian White Ibis and spoonbills (Ciconiiformes) only occurred at wetlands which did not dry fully between floods. Briggs *et al.* (1997) found a negative relationship between prior drying and numbers of nests in two species of Ciconiiformes, namely Pacific Heron and Yellow-billed Spoonbill. Crome (1988) also found that most nesting by Darters, cormorants, herons, egrets and spoonbills commenced after the whole wetland had been flooded continuously for over twelve months (Darter, Little Black Cormorant, Royal Spoonbill, Intermediate Egret), or after at least eight months continuous inundation of nest trees following drying (Little Pied Cormorant, Rufous Night Heron, White-faced Heron, Pacific Heron, Great Egret).

Briggs *et al.* (1997) showed that numbers of nests of Pelecaniformes and Ciconiiformes were related to the area of River Red Gum which was flooded for at least four months. The present study has shown that four months flooding under nest sites (River Red Gums) is generally too short for most waterbirds to complete nesting. However, wetlands with large areas of River Red Gum flooded for four months or longer will generally retain water under the nest trees at the edge of the open area for longer than wetlands with small areas of River Red Gum flooded for four months or more.

There are four possible reasons why most Pelecaniformes and Ciconiiformes nested at permanent or near permanent wetlands, and why the number of their nests increased with duration of flooding only at such wetlands. Firstly, the wetlands which dried out between floods may have had limited numbers of nest trees. This was not the case. Suitable nest trees (Briggs and Thornton 1995) were present but not used at the wetlands which dried out. On average however, there were larger areas of live River Red Gum which flooded for four months or longer at the Murrumbidgee wetlands which retained water, compared with the Murrumbidgee wetlands that dried out between floods.

Secondly, waterbirds could have traditional attachments to breeding sites which usually retain water between floods, because nest trees at such sites are usually inundated for longer. Traditional attachments to nest sites occur in at least some of the species of Pelecaniformes and Ciconiiformes (Marchant and Higgins 1990) which bred at our study wetlands. Ogden (1991), working in Florida, proposed that wetlands with controlled water levels had more nests of Wood Storks *Mycteria americana* than wetlands without controlled water levels because the controlled sites more reliably contained water and therefore were more consistently available as nest sites.

Nest trees were inundated slightly longer (one month) on average at the Murrumbidgee wetlands which generally retained water in their open areas than at wetlands which dried out between floods. No nests, or very few (<2) nests, of Ciconiiformes or Pelecaniformes were present at Sunshower (dried out entirely), Uri (dried out entirely) or Webbs (did not dry out entirely) Lagoons where average durations of flooding under nest trees were less than six months.

Thirdly, wetlands which retain water and food (especially fish) permanently, or near permanently, in their deeper, open areas provide foraging areas for waterbirds with young *if water recedes from under the nest tree*. Permanent wetlands also provide feeding habitat for newly fledged young. A fourth possible reason is the presence of water at the permanent wetlands prior to nesting. Food at wetlands with water would allow birds to forage close to their future nest sites, thus saving energy while they are building up their body reserves for breeding, and constructing their nests. Many studies (Butler 1994, references therein) have shown that the number of nests in heron and egret colonies is related to the area of nearby feeding habitat. This explanation assumes birds feed at the site prior to flooding and during subsequent breeding, and that birds can predict when suitable conditions for breeding are about to occur.

The relationships between these waterbirds (Pelecaniformes and Ciconiiformes) and nesting at the permanent wetlands is probably a combination of the second, third and fourth possible explanations. The sites with permanent water are used for breeding because they provide more reliable foraging habitat both before and during nesting, and the nest trees tend to have water under them for longer. Therefore, breeding colonies develop there. They then become traditional nesting sites. More birds come to breed at these colonies and fledging success of young is greater. Longer floods under the nest trees at these sites encourage more waterbirds to nest there.

MANAGEMENT GUIDELINES

1. River Red Gum and associated areas of open wetland managed for ducks, particularly Pacific Black Duck and Grey Teal, should be allowed to dry out entirely between floods. Following flooding, water needs to remain under the nest trees for at least five months for ducks to complete breeding and for young to fledge.
2. Deeper open areas associated with River Red Gum wetlands managed for waterbirds other than ducks (Darter, cormorants, herons, egrets, Australian White Ibis, spoonbills) should not necessarily dry out between floods. This is especially so if flood durations tend to be short (<5 months), or have been shortened by river regulation and extraction of water for irrigation. The River Red Gum areas should dry between floods. Following flooding, water needs to remain under nest trees for at least 5 and up to 10 months for waterbirds to complete breeding and for their young to fledge.
3. River Red Gum wetlands with manipulated water levels, and which fill from rivers with catchments in the southern part of the Murray-Darling Basin, should be flooded in winter/spring rather than summer/autumn. Nesting in Red Gums by Pelecaniformes and Ciconiiformes occurs one to three months earlier following winter/spring floods, compared with autumn floods. Therefore, it is wasteful and unnecessary to artificially flood these wetlands in summer/autumn for waterbirds, if water is in short supply. This guideline does not necessarily apply to wetlands which fill from rivers whose catchments are in the northern part of the Murray-Darling Basin (see Ley 1998).
4. Continuous, prolonged flooding of River Red Gums should be avoided to prevent death of the trees. They die with over 18 months continuous inundation (Briggs and Thornton 1995; Briggs *et al.* 1997).
5. Waterbirds (Darter, Little Black Cormorant, Little Pied Cormorant, Pacific Heron, White-faced Heron, Great Egret, Little Egret, Intermediate Egret, Rufous Night Heron, Australian White Ibis, Royal Spoonbill, Yellow-billed Spoonbill) nest in River Red Gum trees with certain structural characteristics (most commonly live, mature trees next to open wetland areas, Briggs and Thornton 1995), whose bases are flooded for at least 5 to 10 months but not for more than 18 months. This type of River Red Gum should be conserved, and replacement trees should be encouraged by appropriate silvicultural management (see Briggs and Thornton 1995).
6. Connections between wetlands and rivers should be maintained and managed so that water levels rise and fall as naturally as possible in wetlands, especially under River Red Gums. Wetlands and associated floodplains are an integral part of river systems and hydrological connections between them need to be maintained (Bayley 1991). Water levels in wetlands should not be raised and lowered erratically or rapidly, as this can cause waterbirds to desert their young, River Red Gums to die, and is detrimental to aquatic plants and invertebrates (see Chesterfield *et al.* 1984; Baker-Gabb 1985; Briggs *et al.* 1997). This guideline does not preclude deliberately holding water in open, deeper areas of wetlands, so that these areas stay permanently or semi-permanently inundated (see Briggs *et al.* 1997).

7. A regional or Basin-wide approach needs to be taken to wetland management. Wetlands are managed for a variety of purposes. Not all of these are for conservation. We need to be aware of the ecological needs of wetland plants and animals, and how different wetland management practices affect them. The aim should be to manage for a mosaic of wetlands with different water regimes. Because of river regulation and extraction of water, many wetlands now receive shorter floods than they would have naturally. Other wetlands have been converted into water storages (Seddon and Briggs 1998). Retaining water in deeper, naturally treeless areas of wetlands may partly compensate for reduced flooding caused by river management for irrigation (Briggs *et al.* 1997). Wetlands which dry out entirely between floods provide good breeding habitat for ducks. This is not a reason to entirely dry out wetlands which have been made permanent or near permanent. Rather, water levels in these wetlands should be managed to provide breeding habitat for waterbirds, by allowing the ground under nest trees to flood for adequate periods of time, and then dry back before the next flood, while retaining water in deeper areas of the wetland.

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APPENDIX 1

Scientific names of waterbirds referred to in the text. Great Cormorant were not included in the analyses because they usually nest in dead, rather than live River Red Gums.

Scientific name	Common name
Pelecaniformes	
Anhinga melanogaster	Darter
Phalacrocorax carbo	Great Cormorant
P. sulcirostris	Little Black Cormorant
P. melanoleucos	Little Pied Cormorant
Ciconiiformes	
Ardea pacifica	Pacific Heron
A. novaehollandiae	White-faced Heron
Nycticorax caledonicus	Rufous Night Heron
Egretta alba	Great Egret
E. intermedia	Intermediate Egret
Threskiornis aethiopica	Australian White Ibis
Platalea regia	Royal Spoonbill
P. flavipes	Yellow-billed Spoonbill
Anseriformes	
Tadorna tadornoides	Australian Shelduck
Anas superciliosa	Pacific Black Duck
A. gracilis	Grey Teal
A. castanea	Chestnut Teal
Chenonetta jubata	Australian Wood Duck

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